Dust Plasma Structures in the Inner Coma

Introduction

Comets have been explored from afar with Earth and space-based telescopes, as well as up close with a handful of spacecraft flybys. These investigations have yielded information about the surface geology of comet nuclei, the processes driving cometary activity, the resulting coma and dust and the comet tail's interaction with the solar wind.

From these comet observations, water ice is seen to be the primary volatile that sublimates off the comet nuclei. The distribution of volatiles on the nucleus is not uniform, and most is beneath the top surface where the bulk density is very low, suggesting void space among the ice and dust. Along with the volatiles, dust grains composed of mainly C, H, O and N are also cast off the comet nucleus.

Young et al. presents a two-dimensional model of dust particles surrounded by plasma. These dust grains acquire an electrical charge and in turn affect the behaviors of the plasma such as plasma wave propagation. The dust grains acquire a charge from an electrical current into or out of the grain. Time rate of change of the electrical charge on a particular grain is equal to the total current into the grain. Types of current include the photoelectron current, ion current, primary electron current, secondary electron current, (total current is sum of all these). Ions in cometary plasma contribute to a positive current, and free electrons contribute to a negative current. Due to electron thermal speeds being greater than ion thermal speeds (for comparable electron and ion temperatures), the dust grains tend to charge negatively. As these grains become charged, they take on a finite voltage with respect to the surrounding plasma, attracting or repelling other charged particles. After sufficient time the grain charge and potential reach equilibrium values where the total current reaches 0 (or ion current = electron current).

A previous one-dimensional model by Harvens et al. Showed that the charge on an individual grain within a cloud of grains is reduced in comparison with an isolated grain. More precisely, the charge on a grain is reduced if many grains are present with separations less than or close to the Debye length. This led to the development of the “P parameter” which takes into account the ambient plasma temperature (in eV), density and the dust grain size and density/distribution. For low dust density and $P<<1$ dust grains act as if they are isolated. For high dust density and $P>1$ the collective dust effects can be taken into account.

Wilson (The electrostatic charging of thin dust clouds, JGR, 1988) looked at the charging process of dust in plasma in a statistical method to attempt to understand the macroscopic structure of a dust cloud within plasma.

Several properties of dusty plasma structures are investigated by Vasut et al. (2003) including edge effects of one and two dimensional dusty plasma clouds and oscillations of these systems. The results of running simulations showed the dependance of edge effects of a system in equilibrium on initial conditions. For dynamic oscillating clouds of dusty plasma, dust size distribution and charge had the most pronounced effect. These oscillations would be seen in a system moving towards equilibrium and where plasma conditions are rapidly changing.

Looking into the environment of a comet's inner coma can reveal if dusty plasma structures (like the ones created in labs and in simulations) exist naturally in the comet environment. These structures could have effects on the rest of the comet tail structure. According to a NASA Small Bodies Assessment Group report on the study of comets in the 2011-2020 time frame, listed among their top-level scientific goals were to develop a better understanding of comet composition and structure. Understanding these factors can contribute to solar system science since it is thought that these primitive bodies might reflect the early solar nebula.

        i. Challenges: There is a limited amount of data from within the inner coma of comets from only a handful of flyby missions. Rosetta, currently en route to its target, could provide even more information once it is in orbit around the comet. There are many variables that a coulomb lattice structure of dusty plasma would depend on.

    b. My specific research question/s
        i. Problem definition/hypothesis to address challenge: Does the dusty plasma environment of a comet's inner coma follow any coulomb lattice like structure? And how does this environment depend on factors such as dust grain properties and plasma/dust ratios?
        ii. What is the phenomena being studied? Are there plasma structures within the inner coma such as coulomb lattices?
        iii. What new information might be added to the scientific community from this study?

2. Methodology
    a. Approach – description of experimental techniques proposed and what information they will provide about the system of study, what information might they provide to confirm the hypothesis?
        i. Develop/build a 3-dimensional model of a dusty plasma cloud within a comet's inner coma following the method of Vasut et al.
        ii. Test model with different initial conditions:
            1. particle size distribution
            2. ambient plasma properties (static/dynamic)
        iii. Compare the results of PDS SBN data from spacecraft flybys.
    b. Data needs
        i. Assumptions
            1. For building the model
            2. For interpreting results
        ii. Measured Data
            1. For building model
            2. For interpreting results
        iii. Calculated Data
            1. For building model
            2. For interpreting results
    c. Analytic techniques
        i. Techniques to be used (specific)
        ii. Tools to be used (specific)
    d. Plans for interpretation of results
        i. How are the results from the models going to be compared to measured data?

3. Data
    - a. Target(s)
        - i. Why that target?
        - ii. Which spacecraft:
            - 1. What types of measurements from spacecraft?
    - b. Measured Variables
        - i. Cometary ion production rate
            - 1. dependencies
        - ii. Cometary plasma properties
            - 1. dependencies
        - iii. Dust properties
            - 1. dependencies
    - c. Calculated Variables (Measured à Model à Calculated)
        - i. Model of dusty plasma structures
4. Research Plan (Timeline)
    - a. Goal of research
        - i. Questions to be answered
        - ii. Does the measured data fit the model?
5. References